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Dated 16 March 2004

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APPLICANT: Steven Thomas KNIGHT et al.
APPLICATION NO.: New U.S. Application
FILED: April 23, 2004
FOR: OPTIMISATION OF THE DESIGN OF A COMPONENT
ATTORNEY DOCKET NO.: 119481

Patents Form 1/77

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1. Your reference PAT/AT/3173

2. Patent application number *(The Patent Office will fill in this part)* **0313599.3** 13 JUN 2003

3. Full name, address and postcode of the or of each applicant *(underline all surnames)*

ROLLS-ROYCE plc
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GREAT BRITAIN

Patents ADP number *(if you know it)* 3970002

If the applicant is a corporate body, give the country/state of its incorporation GREAT BRITAIN

4. Title of the invention OPTIMISATION OF THE DESIGN OF A COMPONENT

5. Name of your agent *(if you have one)*

"Address for service" in the United Kingdom to which all correspondence should be sent *(including the postcode)*

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Patents ADP number *(if you know it)* 3470005

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Country	Priority application number *(if you know it)*	Date of filing *(day / month / year)*

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Number of earlier application	Date of filing *(day / month / year)*

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a) any applicant named in part 3 is not an inventor, or
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Description	9
Claim(s)	4
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Statement of inventorship and right to grant of a patent *(Patents Form 7/77)*	NO
Request for preliminary examination and search *(Patents Form 9/77)*	~~YES~~ THE P
Request for substantive examination *(Patents Form 10/77)*	NO
Any other documents *(please specify)*	NO

11. I/We request the grant of a patent on the basis of this application.

Signature V J BIRD

Date 13 JUNE 2003

12. Name and daytime telephone number of person to contact in the United Kingdom

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DUPLICATE

OPTIMISATION OF THE DESIGN OF A COMPONENT

This invention relates to a method of optimising the design of a component. More specifically, although not exclusively, the invention relates to the automation and optimisation of the design of a component using an image data capture means, a computer based finite element analysis (FEA) system, a computer aided analysis system and a method of transferring data between them.

It is known to use FEA systems when designing a component. It is also common practice to use empirical data as a basis for defining boundary conditions and properties of a component defined by a FEA model. Having defined the boundary conditions a finite element model may be imported to an analysis program to determine the suitability and limits of the design. Such analysis programs may be for analysing, for example, computational fluid dynamics, thermo-mechanical properties or mechanical properties.

Empirical data may be collected from instrumentation located on or directed towards the component. Alternatively data derived from electromagnetic radiation (e.g. visible light, Infra-red, Ultraviolet) reflected off or emitted from a component. In some cases, such as with a component coated in a temperature indicating paint, data may be transferred from the component to the FEA system by a number of means.

One method entails the manual tracing of temperature contours on the coated component which are then loaded into an imaging package. The user traces around the temperature contours on the component, assigning a value to each of the contours, thereby producing a 2D temperature contour map of the surface of the component which can be converted manually into a table relating positions on the surface to a temperature value which can be entered into the FEA system. Alternatively the manually traced contours can be converted manually to a 2D array defining the surface properties of the component.

The above process is time consuming and prone to error.

Empirically obtained 2D image data may also be mapped onto a 3D FEA model using conventional 2D to 3D mapping mathematics. Published material to date indicates this has only been achieved to the levels of accuracy required by use of complex and labour intensive processes.

Additionally, when more than one 2D data set is mapped onto the 3D computer model, for example images captured from different viewpoints, then there will be regions where for a given position on the 3D model, there may be more than one empirical value.

Conventionally in the regions where the 2D data sets overlap ambiguities are resolved by averaging the 2D data. However this will lead to errors where at a given co-ordinate, the angle of view for one data set may result in an erroneous data value which is substantially different to a data value captured from a different viewpoint.

According to the present invention there is provided a method of optimising a design of a component comprising the steps of:

a) representing surface properties of said component as at least one 2D image defined by at least one 2D dataset which comprises a plurality of data values,

b) representing said component as a 3D computer model having a surface defined by a plurality of nodes, said nodes further defining a plurality of polygonal elements,

c) defining at least six features common to both the at least one 2D image and the 3D computer model,

d) identifying nodal co-ordinates common to the 2D data and the 3D computer model.

Preferably the method further comprises the step of assigning data values from at least one nodal co-ordinate in the 2D data set to the associated nodal co-ordinate in the 3D computer model.

Preferably the method further comprises the step of mapping the at least one 2D data set onto the 3D computer model such that the properties of the 3D model surface comprise the 2D dataset.

Preferably the method further comprises the step of mapping the at least one 2D data set onto the 3D computer model such that geometric features of the 3D model surface comprise the 2D dataset.

Preferably the surface properties of said component are stored as at least two 2D data sets and represented as at least two 2D images.

Preferably ambiguities between values from the at least two 2D data sets assigned to common nodes, said nodes defining polygonal elements common to both 2D data sets, are resolved by a further method comprising the steps of::

a) determining an apparent area of said common polygonal elements from each of the at least two 2D datasets which contain an ambiguous value,

b) using the data value from the 2D dataset associated with the common polygonal element having the greater apparent area.

Preferably the 3D model is employed in at least one analysis to optimise the design of the said component.

The invention is a method for optimising the design of a component, a method of manufacturing a component comprising the design optimisation steps described herein, the resultant component, a computer program product comprising code to carry out the

design optimisation steps and a computer system adapted to carry out the design optimisation steps herein described.

As previously described empirical data relating to a component may be collected from a number of sources including, but not limited to, components coated with temperature indicating paint(s), pressure sensitive paint(s), vibration analysis, instrumentation (by way of non limiting example, strain gauges, pressure gauges, flow indicators, pyrometers. Such data may be used in the analysis of the component, acting as a basis for the boundary conditions of a 3D computer model of the component. This analysis may be used in either validating or modifying the design of the component and consequently aiding in the optimisation of the component.

The invention provides a means for extracting empirical data values from a 2D data set and assigning them to nodal co-ordinates in a 3D computer model such that the data value for a given location on the component relates precisely to the same location on the 3D FEA computer model of the same component.

The invention also provides a means to transfer geometric features present in the 2D image data set to the 3D model.

When images are taken of a 3D object, the images are encoded as a 2D data set representation of a particular view of the 3D object. In obtaining a collection of 2D data sets which cover the full surface of the 3D object, there are regions of overlap. Consequently there are regions where there is more than one 2D data value for a particular region of the 3D component.

It will be apparent to one skilled in the art that an image taken normal to a surface will reveal the best information on variation of surface properties since, by way of non limiting example, it may be less distorted, and consequently will be clearer than an image taken at an angle to a normal to a surface. Clearly if a surface is curved, there will be surface regions that are not aligned to the image viewing direction and the loss of clarity will be exacerbated.

If visual data is captured from, by way of non limiting example, a turbine stator segment for a gas turbine engine, it will be appreciated that a plurality of views of the turbine blade will have to be captured in order to collect a sufficiently complete map of the surface. A turbine stator segment has a complex shape, comprising an aerofoil having a leading and trailing edge, a pressure side and a suction side both having an arcuate shape, plus an inner and an outer shroud. There will be points of overlapping data values in each "view" and a means to determine which data is most likely to be the most accurate data is required.

If the data captured is, by way of non limiting example, that of temperature indicating paint, it will be apparent to one skilled in the art that confidence in the accuracy of data derived from a 2D image of a component is maximised when the image is captured normal to the component surface. It will also be appreciated that confidence in the accuracy of data derived from a 2D image of a component is reduced when the image is captured at an angle to the normal of the component surface.

Having assigned data values from the 2D data set onto the corresponding nodal co-ordinates of the 3D computer model, the present invention determines the regions of data overlap and calculates the apparent areas of the polygonal elements, the polygonal elements being defined by the nodal co-ordinates, for the 2D data set based on the view from which the 2D image was captured. Hence the same element viewed at a normal to the surface of the element will have an area apparently larger than the same element viewed at an angle to the normal. The larger the apparent area of the polygonal element, the closer to the normal the 2D image was captured from. Hence the data corresponding to the polygonal element will be the most accurate data value. Hence ambiguities between data values in overlapping data sets are resolved.

For a better understanding of the present invention and to show how it may be carried into effect, reference will now be made by way of example to the accompanying drawings in which:

Figure 1 shows image data capture apparatus arranged around a component;

Figure 2 represents a 2D image (a first 2D data set) of the component as viewed in the direction of arrow "A" in Figure 1;

Figure 3 shows a 2D image (a second 2D data set) of the component as viewed in the direction of arrow "B" in Figure 1;

Figure 4 represents a finite element 3D computer model of the component;

Figure 5 represents a view of the 3D computer model as viewed in the direction of arrow "A" in Figure 4; and

Figure 6 represents a view of the 3D computer model as viewed in the direction of arrow "B" in Figure 4.

Figure 7 is an enlarged view of element 60a as indicated in figure 5.

Figure 8 is an enlarged view of element 60b as indicated in figure 6.

Figure 1 shows a component 10 located on a surface 12. A camera 14 is employed to capture 2D image data from different view points around the component 10.

In this non limiting example the component 10 is a turbine stator segment 16 comprising an inner shroud 18, an outer shroud 20 and an aerofoil section 22 fixed between the shrouds 18,20.

The aerofoil section 22 comprises a suction side 24 and a pressure side 26 (hidden from view) brought together by a leading edge 28 and a trailing edge 30.

Although it would be obvious to one skilled in the art to capture a plurality of 2D images, for reasons of clarity the description will focus on two 2D images, which are

represented in Figure 2 and Figure 3 as views on the component 10 as viewed in the direction of arrow "A" and arrow "B" respectively.

The two 2D images are encoded as 2D data sets. Hereafter the 2D data set derived from the end on view as shown in Figure 2 is referred to as the first 2D data set and the 2D data set derived from the side on view as shown in Figure 3 is referred to as the second 2D data set. In this non limiting example the component 10 is coated in a temperature indicating paint 31 which after exposure to engine running conditions, results in regions of different colour 31a-d on the component 10 surface. Hence the 2D data sets comprise the co-ordinates of the different temperatures recorded on the surface of the component 10.

Shown in Figure 4 is a representation of a 3D computer model 32 of the component 10, the surface defined by a plurality of polygonal elements 34 defined by nodes 35. In order to establish a mapping link between the 2D data set and the 3D computer model 32 at least six features common to both the 3D model and the 2D data set being mapped must be identified.

The user orientates the 3D computer model 32 such that the view is similar, but not necessarily identical, to that displayed in the 2D image. Hence in mapping the first 2D data set, the 3D model 32 may be orientated as shown in Figure 5. Likewise, in mapping the second 2D data set, the 3D model 32 may be orientated as shown in Figure 6. The computer model 32 need only be orientated in a way that allows a clear view of the area where a lock point is to be placed. Therefore the user may freely rotate and translate the 3D model 32 before, during and after the process of lock point selection.

Referring to Figures 2 and 5, and by way of non limiting example, six common features are indicated at 36,38,40,42,44,46.

Referring to Figures 3 and 6, and by way of non limiting example, the six common features are indicated at 48,50,52,54,56,58.

Knowing the position of the lock points for six features 36 to 46 or features 48 to 58 in both the 3D model space and the 2D image space it is possible to solve a set of mapping equations to allow additional points whose positions are only known in one space to be moved between the 2D data set or the 3D model.

The surface of the 3D computer model is defined by polygonal elements 34 which may vary in size over the surface of component 10. Once defined, the elements 34 do not change in size for a given iteration of an analysis. In figures 5 and 6 an element 60 common to both the first and second data set is highlighted, indicated as 60a and 60b respectively. In this example element 60 has data values from both the first and second 2D data set.

Referring now to Figures 7 and 8 the regions surrounding element 60 in figures 5 and 6 respectively are presented as enlarged views. The element 60a (which is element 60 viewed from direction "A") has an area apparently smaller than element 60b (which is element 60 viewed from direction "B"). The data associated with the element 60 having the greater apparent area is used in preference to the data associated with the element 60 having the smaller apparent area. Hence in regions where there is more than one data value per nodal co-ordinate, the data value which is most likely to be the most accurate can be chosen, thereby resolving ambiguities in data values from different 2D data sets.

While the 3D model will normally contain all the nominal features of the component, there may be instances where the component is provided with extra features, perhaps because of a variation in the manufacturing process or because component was altered in order to fit instrumentation. It will be appreciated that the present invention may also be employed to transfer geometric features present in the 2D image data set to the 3D model by a method analogous to that hereinbefore described.

It will be appreciated that the present invention permits automation of the data capture process, hence saving time and effort when a plurality of components of substantially

identical geometries are being interrogated. It has been found that if 2D image data is captured from the same view points for each of the components, then the lock points need only be defined for each view and not for each image taken from a common viewpoint. In order to facilitate this the components and image capture device may need to fixed in a suitable jig arrangement such that each of the components are presented in the same relative orientation to the image capture device.

It will be appreciated that the present invention may also be employed to aid in the visualisation of empirical data, thereby enabling a user to determine properties and behaviour of the component when in use. This may significantly aid in the further development or the component or in establishing its operational parameters.

It will be appreciated that any component may be the subject of the optimisation hereinbefore described and need not be limited to the field of gas turbine engines.

The configurations shown in Figures 1 to 8 are diagrammatic. The component under interrogation, its orientation, configuration and the data type being captured may vary. Likewise, the mesh patterns, size and spacing will vary between for different components and finite element analysis packages.

CLAIMS

1 A method of optimising a design of a component comprising the steps of:

a) representing surface properties of said component as at least one 2D image defined by at least one 2D dataset which comprises a plurality of data values,

b) representing said component as a 3D computer model having a surface defined by a plurality of nodes, said nodes further defining a plurality of polygonal elements,

c) defining at least six features common to both the at least one 2D image and the 3D computer model,

d) identifying nodal co-ordinates common to the 2D data and the 3D computer model.

2 A method as claimed in claim 1 wherein the method further comprises the step of assigning data values from at least one nodal co-ordinate in the 2D data set to the associated nodal co-ordinate in the 3D computer model.

3 A method as claimed in claim 1 or claim 2 wherein the method further comprises the step of mapping the at least one 2D data set onto the 3D computer model such that the properties of the 3D model surface comprise the 2D dataset.

4 A method as claimed in any one of the preceding claims wherein the method further comprises the step of mapping the at least one 2D data set onto the 3D computer model such that geometric features of the 3D model surface comprise the 2D dataset.

5 A method as claimed in any one of the preceding claims wherein the surface properties of said component are stored as at least two 2D data sets and represented as at least two 2D images.

6 A method as claimed in any one of the preceding claims wherein ambiguities between values from the at least two 2D data sets assigned to common nodes, said nodes defining polygonal elements common to both 2D data sets, are resolved by a further method comprising the steps of:

a) determining an apparent area of said common polygonal elements from each of the at least two 2D datasets which contain an ambiguous value,

b) using the data value from the 2D dataset associated with the common polygonal element having the greater apparent area.

7 A method as claimed in any one of the preceding claims wherein the 3D model is employed in at least one analysis to optimise the design of the said component.

8 A method as claimed in any one of the preceding claims wherein the at least one 2D data set is derived from a 2D image of said component.

9 A method as claimed in any one of claims 1 to 8 wherein the at least one 2D data sets are image data of said component coated with at least one temperature indicating paint.

10 A method as claimed in claims 1 to 8 wherein the at least one 2D data sets are image data of said component coated with at least one pressure sensitive paint.

11 A method as claimed in claims 1 to 8 wherein the at least one 2D data sets are data derived from vibration analysis.

12 A method as claimed in claims 1 to 8 wherein the at least one 2D data sets are data derived from pyrometry measurements

13 A method of optimising a design of a component as substantially hereinbefore described with reference to the accompanying drawings.

14 A method of manufacturing a component, the method comprising the step of optimising the design of the component by a method in accordance with any one of claims 1 to 13.

15 A method of manufacturing a component as claimed in claim 14 wherein the component is a component of a gas turbine engine.

16 A method of manufacturing a component as claimed in claim 15 wherein the component is a turbine stator segment, the design of said turbine stator segment being optimised by a method in accordance with any one of claims 1 to 13

17 A method of manufacturing a component as claimed in claim 15 wherein the component is a turbine blade, the design of said turbine blade being optimised by a method in accordance with any one of claims 1 to 13

18 A component having a design optimised by a method in accordance with any one of claims 1 to 13.

19 A component manufactured by a method comprising the step of optimising the design of the component by a method in accordance with any one of claims 1 to 13.

20 A computer program product comprising code for carrying out a method in accordance with any one of claims 1 to 13.

21 A computer system adapted to carry out a method in accordance with any one of claims 1 to 13.

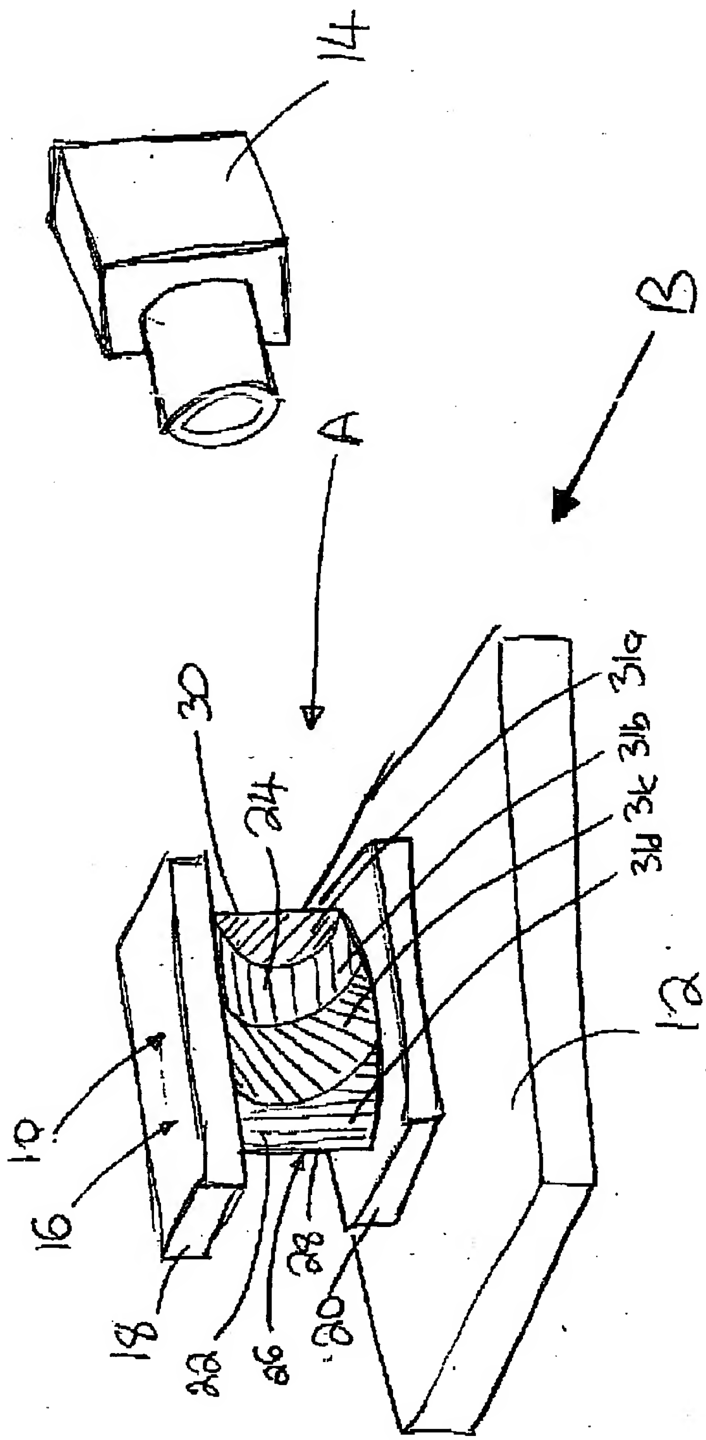

Figure 1

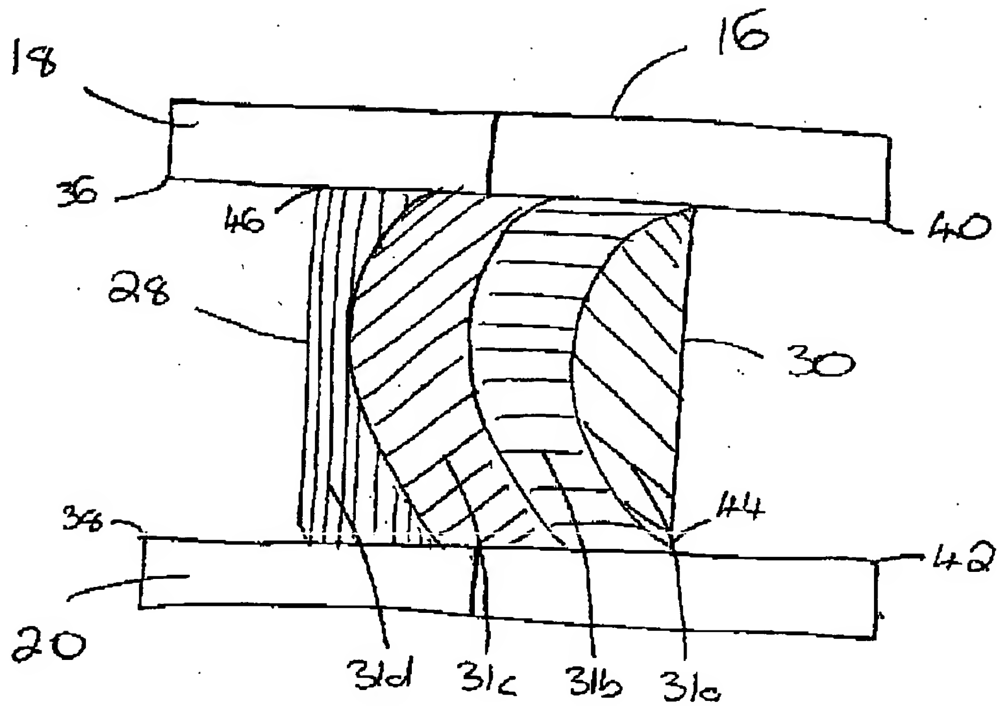

Figure 2

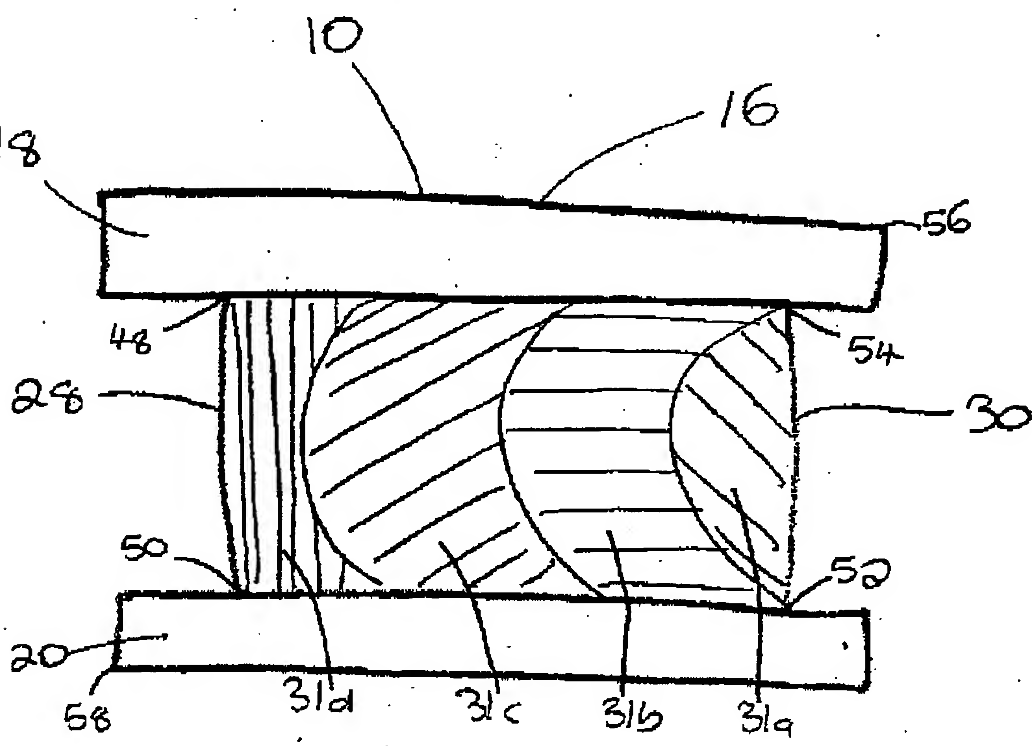

Figure 3

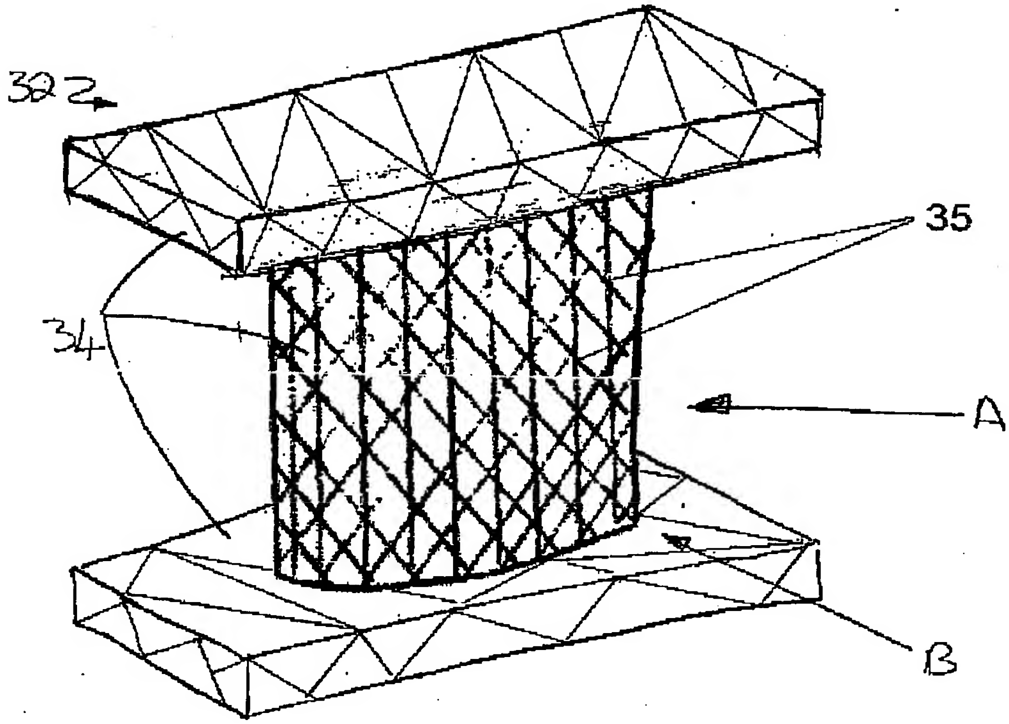

Figure 4

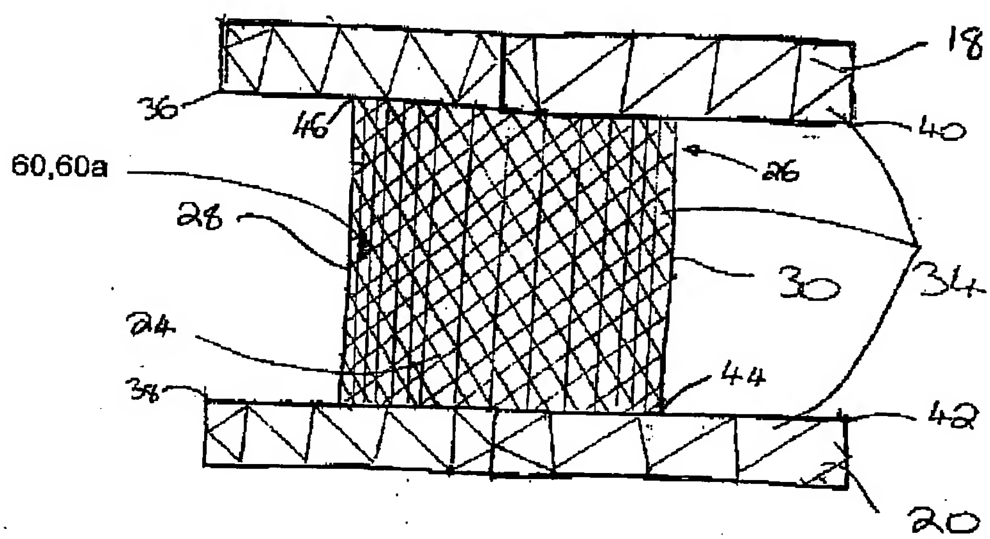

Figure 5

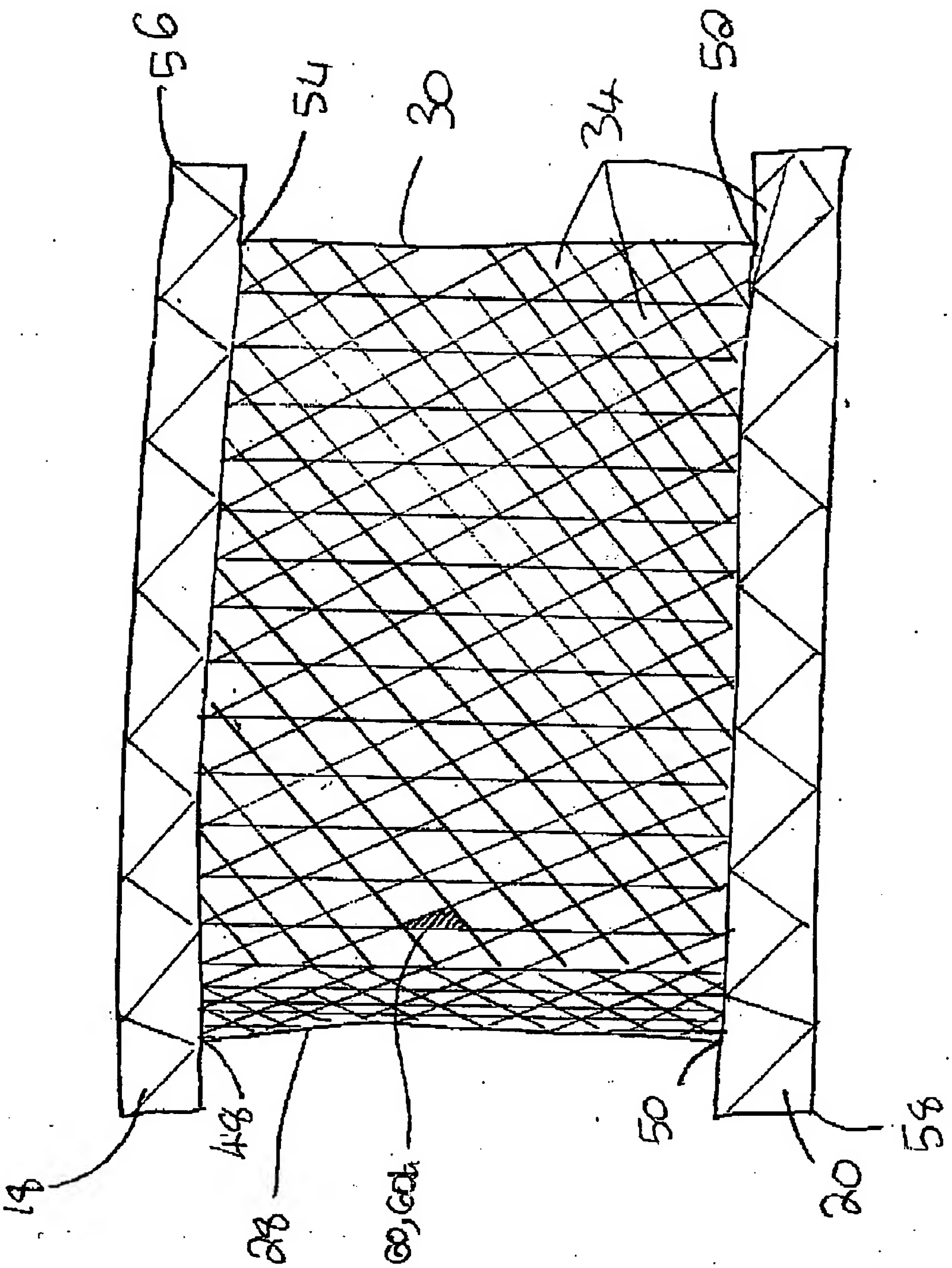

Figure 6

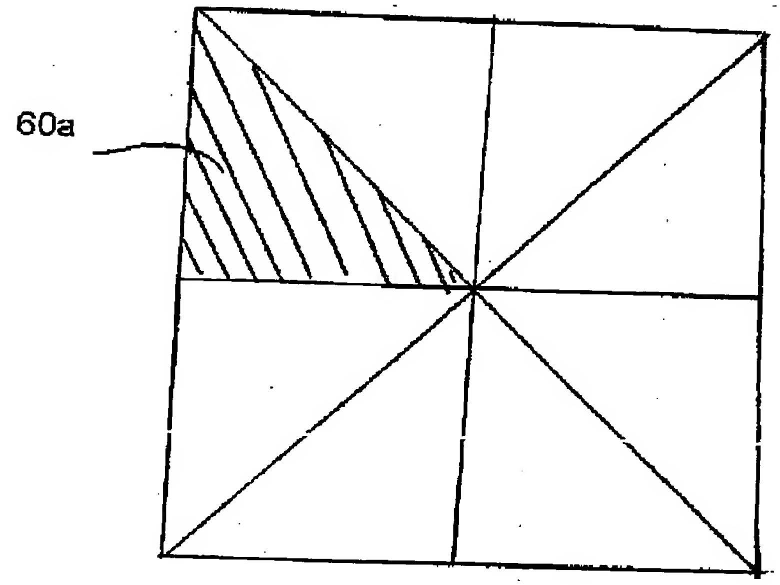

Figure 7

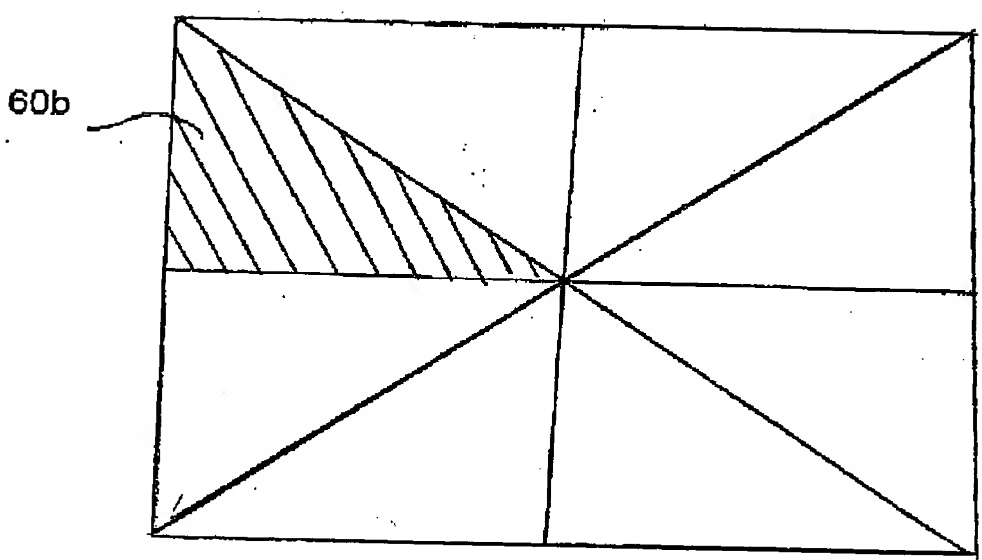

Figure 8